Moderate Exercise Improves Gait Stability in Disabled Elders

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ABSTRACT. Krebs DE, Jette AM, Assmann SF. Moderate exercise improves gait stability in disabled elders. Arch Phys Med Rehabil 1998;79:1489-95.

Background: Decreased muscle strength impedes elders' functional performance in daily activities such as gait. The mechanisms whereby increased strength improves gait are unknown.

Methods: A prospective, blinded, randomized trial of moderate intensity strength exercise was conducted and its impact was measured on functional mobility during gait in 132 functionally limited elders. Lower extremity strength was measured, including hip abductor, hip extensor, and knee extensor strength. Of the 132 subjects, 120 subjects (mean age, 75.1yrs) completed 6 months of elastic band resistance training at least 3 times a week or served as no-exercise controls.

Results: Subjects increased their lower extremity strength in the exercise and control groups, by 17.6% and 7.3% ($p < .01$), respectively. Gait stability improved significantly more in the exercise group than in the control group ($p < .05$). Increases in forward gait velocity were not significantly different between groups. Peak mediolateral velocity and base of support improved in the exercise group, but not in the control group. Change in lower extremity strength correlated significantly but weakly with many of the gait variables.

Conclusions: Gait stability, especially mediolateral steadiness, improved in the exercise group but not in the control group. These results show that even moderate strength gains benefit gait performance in elders and thus provide a sound basis for encouraging low-intensity strength training for elders with functional limitations.

LITTLE IS KNOWN about the functional benefits of strengthening exercises in older persons, despite the obvious appeal of such a commonsense notion. Buchner and deLateur[1,2] suggest that strength below a threshold value would prevent or greatly slow walking; strength improvements above a threshold value would not enhance walking function. Several studies suggest that strengthening programs improve strength in elderly populations.[3-6] Aniansson[7] and Fisher and colleagues[8] found direct relationships between gait velocity and knee strength in healthy elders. Iverson and associates[9] provided self-report data showing that healthy elders' ability to perform activities of daily living was improved after an exercise regimen. Whipple and associates[10] found significantly lower peak torque and power of lower extremity muscles in a group of elders who sustained a fall compared with a nonfall control group.

The relation between functional gain and strength improvement among functionally limited elders is poorly understood. Lord and coworkers[10] used retrospective data to suggest that strength exercises engender better balance and gait in women age 57 years and older. Gehlsen and Whaley,[12] however, reported a low correlation ($r = .19$) between balance and strength outcomes in elderly subjects divided into "fallers" and nonfallers. Judge and colleagues[13] reported that gait measures improved insignificantly among 31 exercising elderly subjects (mean age, 82.1yrs), self-selected gait velocity improved 8%, and maximal gait speed increased only 4%. Judge and associates[14] found that combined exercise training (resistance exercise, brisk walking, postural control, and flexibility exercises) produced improved balance outcomes compared with flexibility exercise training in 21 women (mean age, 67.8yrs). The extent to which potentially destabilizing postural compensations for weakness,[15,16] such as excessive center of gravity mediolateral motion or mediolateral base of support width,[17,18] are ameliorated after strength gains has not been reported. Fiatarone and coworkers[19] reported nearly trebling quadriceps muscle strength with an 8-week high intensity strengthening exercise, but no changes in functional status were reported, although tandem walking velocity improved slightly ($p = .05$). Given the substantial lifestyle changes needed to effect the mean of 174% strength changes, it is unlikely that most elders would consider such small functional benefits sufficient to justify participation. It also is possible, however, that gross performance measures such as walking speed are not sensitive to subtle changes that lead to more stable gait.

Although walking speed is important to elders' functional independence in locomotor activities of daily living, safe and stable gait is arguably more critical to independence. Thus, in addition to examining changes in preferred walking speed, we examined gait mediolateral center of gravity stability and mediolateral base of support during both self-selected walking and in cadence-controlled gait. Preferred gait permits subjects to select their own walking pace, but variables other than gait speed may be confounded by gait velocity. Cadence-controlled gait permits investigation of variables such as double support time and mediolateral stability that are relatively free from the confounding effects of velocity variations.[16-18]

We report here the largest group of functionally limited elders to have participated in both a strength enhancing experiment and in sophisticated whole-body gait analysis. We hypothesized that significant improvements in the postural motions used to compensate for lower limb weakness would be found after 6 months of participation in a home-based strength training program.

METHODS

We conducted a prospective, single-blinded, randomized trial of 6 months of moderate exercise versus no-exercise controls in functionally limited elders. Baseline measures of functional

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mobility were obtained on 132 elders (mean age, 74.3 years), of whom 120 returned for 6 month follow-up testing.

Subjects

Subjects were recruited from 215 community dwelling participants in a strength training experiment (see Jette and colleagues[21] for details). Included in the study were elders who indicated during a telephone screening interview that they were willing to participate in the strength training experiment. All were at least 60 years old, reported one or more functional limitations in the SF36 physical function scale (excluding the vigorous activity item),[20] had no medical history that would be a contraindication for exercise, were not receiving rehabilitation services, were ambulatory with or without assistive devices, and indicated a willingness to come to the our biomotion laboratory for the 1.5-hour locomotion tests. Of the 215 eligible, 56% reported 3 or more areas of limitation in the SF36, 25% reported 2 areas, and 19% reported 1 area on the SF36; 132 consented according to the guidelines of the MGH Institutional Review Board and had a baseline gait evaluation. Of these 132, 120 completed both the baseline and 6-month visits. Dropout rates were similar in the two groups and were thus not systematically related to exercise or control interventions. Table 1 summarizes the patient demographic characteristics; the sample characteristics are virtually identical to those of the 215 subjects.[21] Tables 2 and 3 describe the diagnostic groups judged by a physician to have most likely caused the patient's impairment, as well as the number of diagnoses per subject. Most subjects had arthritis-related impairments, but the sample is heterogenous and did not differ between the exercise and control groups. Medications were not recorded, but we assume that because this was a randomized trial and the groups were roughly equal in all demographic and diagnostic categories, medication status would not differ appreciably.

Instrumentation

The kinematic system, an 11-segment whole body model, is described in detail elsewhere.[16-18] Briefly, simultaneous bilateral whole body kinematic data are collected with a motion analysis system using Selspot II hardware[a] and analyzed with Telemetered Rapid Acquisition of Kinematics (TRACK) kinematic software[b] and software developed in our Biomotion Laboratory. Light-emitting diode arrays are mounted on 11 body segments: right and left feet, shanks, thighs, and arms, and the pelvis, trunk, and head. The system calculates the six-degree-of-freedom position of each body segment within a 2 × 2 ×

Table 1: Descriptive Data for the 120 Participants With Both Baseline and 6-Month Visits

	Exercise Group	Control Group	Total Group	Range*
Demographics				
Sex				
M	19	12	31	
F	35	54	89	
Age (yrs)	74.83 ± 7.33	74.15 ± 5.77	74.46 ± 6.50	(62-89)
Height (m)	1.63 ± .09	1.61 ± .09	1.62 ± .09	(1.42-1.91)
Weight (kg)	69.36 ± 12.97	69.69 ± 12.29	69.54 ± 12.55	(43-113)
BMI (kg/m^2)	26.03 ± 4.59	26.77 ± 4.10	26.44 ± 4.32	(18-43)
Strength				
Knee extension (kg)	14.06 ± 4.76	14.33 ± 4.44	14.21 ± 4.57	(6.25-28.50)
Hip abduction (kg)	8.86 ± 2.55	8.29 ± 2.34	8.54 ± 2.44	(3.35-17.10)
Hip extension (kg)	12.04 ± 3.96	11.44 ± 4.04	11.71 ± 4.00	(3.55-24.15)
Lower extremity (kg)	34.96 ± 9.75	34.05 ± 9.38	34.46 ± 9.52	(15.65-58.95)
Free gait				
Cycle time (sec)	1.11 ± .13	1.10 ± .11	1.11 ± .12	(.88-1.54)
Double support (% cycle)	14.66 ± 3.28	15.06 ± 2.79	14.88 ± 3.01	(9.04-31.73)
Stance (% cycle)	63.53 ± 3.28	63.84 ± 2.95	63.70 ± 3.09	(56.21-78.46)
Peak AP velocity (cm/sec)	114.84 ± 24.41	112.16 ± 26.91	113.35 ± 25.75	(28.12-183.54)
Average AP velocity (cm/sec)	102.96 ± 22.85	100.68 ± 25.41	101.69 ± 24.23	(23.49-166.82)
Maximum moment arm (cm)	17.83 ± 3.91	17.00 ± 3.99	17.37 ± 3.96	(7.54-29.06)
Peak ML CG-CP separation (cm)	6.18 ± 2.01	6.57 ± 1.88	6.39 ± 1.94	(1.01-12.98)
Peak ML velocity (cm/sec)	18.70 ± 4.86	19.57 ± 4.94	19.19 ± 4.91	(7.42-34.86)
CG ML excursion (cm)	5.67 ± 3.06	5.53 ± 2.59	5.59 ± 2.80	(.87-13.77)
ML base of support during double support (cm)	15.28 ± 5.28	15.22 ± 4.38	15.25 ± 4.78	(2.77-27.26)
Paced gait				
Cycle time (sec)	1.03 ± .05	1.05 ± .06	1.04 ± .06	(.93-1.32)
Double support (% cycle)	13.77 ± 1.88	14.10 ± 2.34	13.95 ± 2.15	(7.96-19.81)
Stance (% cycle)	63.03 ± 2.77	63.54 ± 2.74	63.31 ± 2.75	(59.04-72.77)
Peak AP velocity (cm/sec)	125.62 ± 16.97	119.97 ± 21.77	122.45 ± 19.92	(50.88-164.70)
Average AP velocity (cm/sec)	113.26 ± 15.89	108.07 ± 19.40	110.35 ± 18.05	(44.87-145.59)
Maximum moment arm (cm)	19.18 ± 3.49	18.24 ± 3.86	18.65 ± 3.72	(11.03-29.61)
Peak ML CG-CP separation (cm)	6.82 ± 2.31	6.62 ± 1.83	6.71 ± 2.05	(2.06-12.40)
Peak ML velocity (cm/sec)	20.15 ± 5.31	19.89 ± 5.09	20.01 ± 5.17	(8.08-34.21)
CG ML excursion (cm)	5.31 ± 2.72	5.33 ± 2.82	5.32 ± 2.76	(.77-14.32)
ML base of support during double support (cm)	15.74 ± 4.48	14.89 ± 4.29	15.26 ± 4.37	(4.64-25.16)

Values are mean ± standard deviation (except for gender).
Abbreviations: BMI, body mass index; AP, anteroposterior; ML, mediolateral; CG, center of gravity; CP, center of pressure.
* Minimum-maximum for the total group.

Table 2: Primary Diagnostic Categories of the 120 Participants

Group	Musculoskeletal	Cardiorespiratory	Neurologic	Other
Exercise	18	21	8	7
Control	30	23	9	4
Total	48	44	17	11

Musculoskeletal diagnoses were composed primarily of arthroses such as degenerative joint disease; cardiorespiratory diagnoses were primarily asthma and emphysema; neurologic diagnoses were primarily diabetic neuropathy and old polio. In cases of polydiagnosis, the patient's physician or self report was used to decide what primarily caused the functional limitation enabling the patient to meet the inclusion criteria; when not available, the project physician used all available evidence to decide.

$2m^3$ viewing volume. System precision is within 1mm in linear displacement and orientation within 1° in angular displacement. Whole body center of gravity location is computed from all 11 segments' kinematic and mass data. Floor reaction forces are acquired from two Kistler™ force platforms[c] and processed on the same computer. Another program determines individual foot and combined centers of pressure with accuracy of <3mm. Kinematic and kinetic data are sampled at 150Hz.

Critical gait control variables were examined in both anteroposterior (forward progression plane) and the mediolateral (left-right) directions (fig 1). Anteroposterior variables included gait speed, cycle time, double support, and single stance as a percent of the gait cycle, and the instantaneous maximum (peak) anteroposterior velocity in a gait cycle. Mediolateral variables included the peak center of gravity–center of pressure mediolateral separation distance, which measure measures how far the body's center of gravity is permitted to deviate from the supporting ground reaction force's center of pressure; the center of gravity mediolateral excursion, which measures left-right body "sway" during gait; the peak mediolateral center of gravity velocity, which measures how rapidly the body sways left to right; and the mediolateral base of support (the mediolateral plane distance between the two foot centers of gravity), which measures how far the feet are apart at heelstrike (fig 1). The base of support is obtained at heel strike. It is important because it represents the initiation of double support phase of gait when both feet are not flat on the ground and the body is in an inherent state of instability; the wider base of support is more stable, but less efficient for forward progression. Whole body moment arm data are computed from the root mean square horizontal distance between the center of gravity and the center of pressure. The maximum value is derived during single limb stance phase, typically just before contralateral heel strike.[15]

Procedures

Intervention. The "Strong for Life" program included a 35-minute videotape program of 11 exercises. Resistance was provided by elastic bands of varying thickness.[21] The intervention was performed for the 6 months between pretesting and posttesting. Both upper and lower limb exercises were performed while seated or standing. Each exercise incorporated diagonal and rotational motions associated with functional movement patterns similar to proprioceptive neuromuscular facilitation patterns. Subjects were asked to increase the resistance, using a thicker elastic band, when they could correctly perform 10 repetitions without significant fatigue. Because the elastic bands provide nonlinear resistance, it is not possible to describe the exact forces (on a ratio or interval level scale) subjects resisted when using a given band. The thicker the band, however, the greater the resistance it provides. Each band clearly provides less stimulus than 100lb of resistance, but, in our experience, each elastic band can provide a challenging physical resistance during each exercise task. A physical therapist taught the home exercise program during the first home visit and provided motivational problem solving to overcome participants' perceived difficulties with the intervention during a second home visit.[21] The initial resistance level was individualized for each participant to provide a challenging 10 repetition exercise stimulus. The therapist was available to the participants for telephone follow-up and to help the patients decide when to increase the resistance. An average of 7.5 telephone contacts per participant were provided during the 6 months.[21] A remarkable 78% of the subjects adhered to the recommended exercise frequency and level of resistance in the intervention group.[21]

Table 3: Polydiagnosis Among the Sample

	Number of Diagnoses					
	1	2	3	4	5	6
Exercisers	8	14	15	14	3	—
Controls	7	23	20	10	5	1
Total	15	37	35	24	8	1

Eighty percent of the subjects had 2 to 4 diagnoses contributing to their impairments and functional limitations.

Strength assessment. A calibrated Nicholas dynamometer[d] was used to assess isometric hip abduction, hip extension, and knee extension using standard manual muscle test protocols, except that subjects were seated for hip abduction and were standing for hip extension. Tests were conducted for seated hip abduction and knee extension, with the hip at 90° and the knee at 60° flexion.[21] Hip extension was tested in standing, with the hip and knee at 0° extension. The subject was asked to push his or her thigh backwards into the dynamometer.[21] All joint angles were obtained with a fixed goniometer prior to testing. The right side was tested unless pain or other impairments prohibited testing; in that case the left limb was tested. Test-retest reliability of hip abduction, hip extension, and knee extension among a random 22-person subsample was ICC = .741, .665, and .479, respectively. Three 3-second trials per muscle were performed. Values from the last 2 trials were averaged for data analysis. Combining the hip and knee scores into a summary score of lower limb strength was done to enhance the stability of the strength estimates.

Gait analysis. Subjects were barefoot and walked without assistive devices. At least 1.5 minutes of rest was given between trials. Several practice trials of each activity were performed before data collection. Two trials each of preferred speed gait and paced gait (120 steps/min) over a 10-m walkway were collected. Preferred gait should reflect movement strategies under self-selected optimal neuromotor control. Paced gait permits valid cadence-controlled within and between subject comparisons.[15-17] Preferred gait was performed first to prevent the preferred cadence from being influenced by the paced cadence. The paced cadence was determined from previous literature and pilot studies to create easily reproduced natural cadences.[16,17] Before preferred gait trials, subjects were instructed as follows: "Move forward in as straight a line as possible, walking at your normal pace, as if you were taking a brisk walk in the park." For paced gait trials, subjects were first asked to walk in place to the beat heard by a metronome set to 120 beats/min. They were then instructed as in the previous preferred gait trials, but to walk to this pace.

Data Analysis

The treatment and control groups were compared with respect to each baseline characteristic using all subjects with

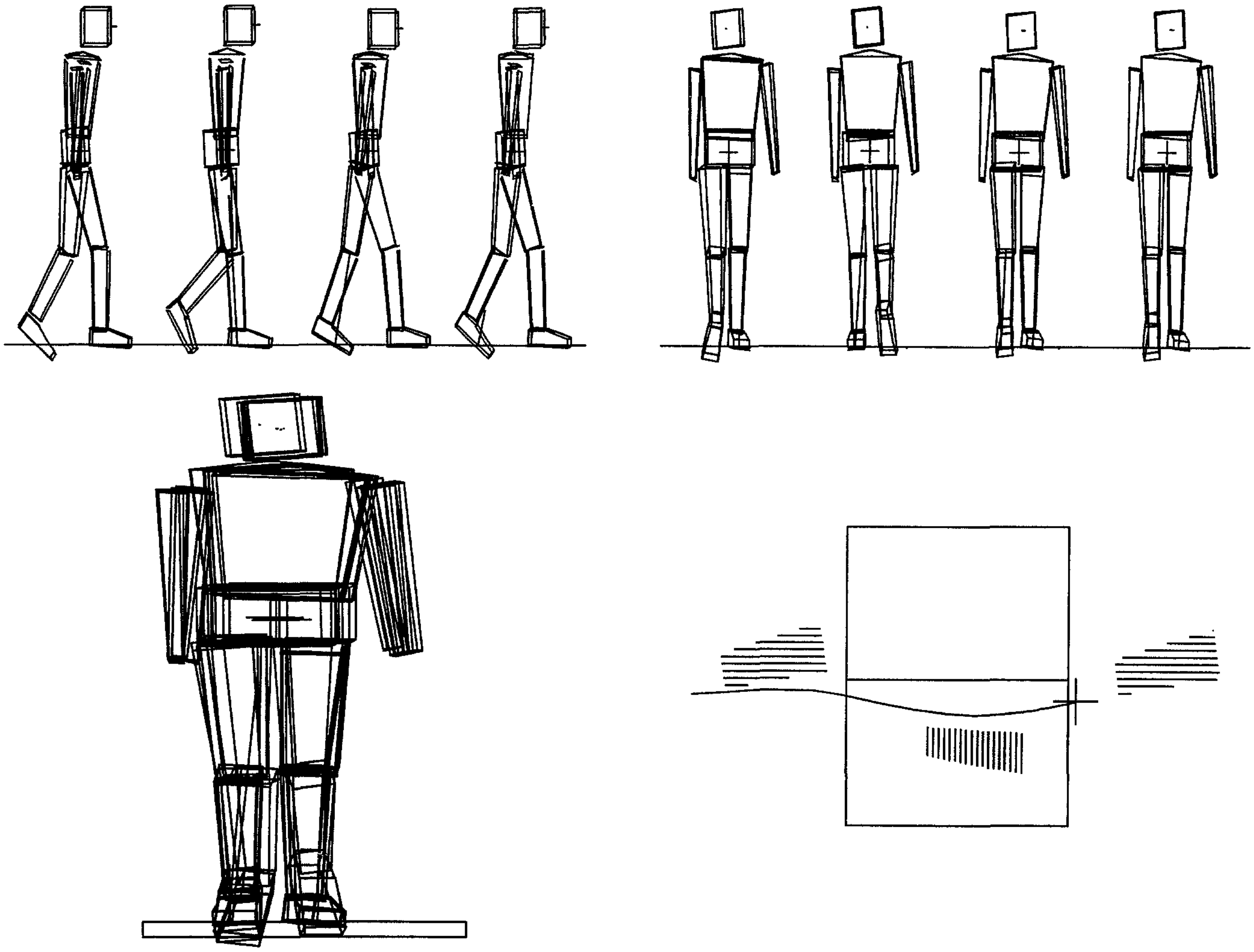

Fig 1. Overview of gait cycle from which the factor analysis data were obtained. Each plot shows the same gait cycle, but computer-rotated to permit easier appreciation of the variables. The top left plot shows a right side view of one gait cycle of a typical elder prior to intervention. The ground reaction force from the right foot is shown as a solid line emanating from the ground. The point at which the ground reaction force intersects the ground is the center of pressure. The horizontal distance from the center of pressure to the center of gravity is the whole body moment arm. The top right plot provides an anterior view demonstrating whole center of gravity (the "+" in the pelvic segment) showing the whole body contributions to mediolateral sway during gait. The bottom left plot superimposes these four androids to provide a quantitative illustration of the amount of mediolateral sway occurring during a gait cycle. Note that all kinematics in this figure are data, not schematics, although the distance between each android is arbitrary. The bottom right plot shows the one right (up/down hatch marks) and two left (right-left hatch marks) foot prints during this gait cycle, indicating the base of support, and the mediolateral center of gravity trace (sinusoidal line between the foot prints) during this gait cycle. The two boxes in the middle of the plot are the left and right force plates.

available data for that characteristic. Means, standard deviations, and Pearson correlations were calculated. Other analyses were carried out on the set of 83 subjects (34 in the exercise group and 49 in the control group with complete gait data at both baseline and follow-up. All analyses were carried out using SAS Version 6.12.[e]

Because the number of available subjects was small relative to the number of variables measured, the planned assessment of treatment efficacy was based on factor scores rather than individual gait variables. The variables entered into the factor analysis were the free and paced gait variables listed in table 1. Principal factor analysis was used to identify coherent groups of variables.[22] The prior communality estimate for each variable was set to the square of its multiple correlation with the other variables. Promax rotation was used to achieve more interpretable factors. A variable was considered to belong to a factor if its factor structure (correlation) with that factor was at least .40 in absolute value and its correlation with all other factors was <.40 in absolute value. Factor scores were then created for each person at each time period as follows.[22] Each variable was standardized to have mean 0 and standard deviation 1 by subtracting the baseline mean and then dividing by the baseline standard deviation. The standardized variables which appeared in a given factor were then added together to create the corresponding factor score (after changing the sign of any variable which appeared with a negative correlation in the factor). Change scores were created by subtracting the baseline score from the six-month score.

Analysis of covariance (ANCOVA) was used to investigate whether 6-month change in each factor score was significantly related to treatment group, after controlling for baseline value and gender. Regression diagnostics were used to identify any overly influential individuals. For any factor score that showed a significant exercise effect at the .05 level, separate ANCOVA models were fit for each gait variable that appeared in that factor. This was done to investigate whether changes were consistent among all variables in that factor. So that the magnitude of the effects of gender and treatment group on the individual variables would be understandable, these models used the variables in their original scales, not the standardized versions of the variables.

RESULTS

Overall lower extremity strength gains of 17.6% and 7.3% ($p < .01$) were realized in the exercise and control groups, respectively (table 4). Two gait factors were statistically identified (table 5). Factor loadings agreed with our a priori hypotheses in that the mediolateral variables loaded on one factor and the anteroposterior variables loaded on the other factor. One factor was related to anteroposterior gait variables. Change in the anteroposterior factor was not significantly different between the exercise and control groups (table 6). The 3% to 5% gait anteroposterior velocity improvements were not significant: gait anteroposterior velocity improved in the exercise group from 102.6 ± 22.9cm/sec to 108.1 ± 23.9cm/sec and in the control group from 100.6 ± 25.6cm/sec to 103.6 ± 27.6cm/sec. At baseline, the 83 subjects included in the ANCOVA were similar to the 49 subjects who did not have complete gait data available.

The greatest effects of the exercise intervention were in the mediolateral stability variables. Whole body center of gravity mediolateral stability improved significantly more in the exercise than in the control group (table 6). Both mediolateral center of gravity excursion and velocity decreased in the exercise group but not in the control group. This mediolateral stability enhancement was also evident in base of support improvements during preferred gait, decreasing 1.0 ± 4.46cm following the exercise intervention but increasing .15 ± 4.32cm in the control group. Center of gravity mediolateral excursion decreased in the exercise group from 6.01 ± 3.17cm to 5.10 ± 2.53cm but changed only from 5.67 ± 2.65cm to 5.25 ± 2.39cm in the control group during the 6-month interval.

Results of the ANCOVA models for change in the two gait factor scores are shown in table 6. The treatment group was not significantly related to change in the anteroposterior factor. After one extremely influential subject was dropped, the treatment group was significantly related to change in the mediolateral factor, with the treatment group having a greater improvement in mediolateral control. Before dropping this subject, the treatment group comparison was borderline significant ($p = .0661$). For each mediolateral variable, the exercise group improved more than the control group.

Good internal consistency was found in the strength measures. Correlations between the total lower extremity strength changes and changes at the hip and knee ranged from .73 to .82 ($p < .01$). Gait variables were also internally consistent; for example, in the exercise group, change in paced gait maximum moment arm correlated $r = .68$ and $-.80$ ($p < .001$) with change in paced gait anteroposterior velocity and double support time, respectively. Total lower extremity strength changes in the exercise group correlated significantly but poorly ($r \leq .40$) with changes in many of the gait variables (table 7).

Table 5: Factor Structure (Correlations) for Baseline Gait Variables Based on the 83 Subjects With Complete Baseline and Follow-Up Gait Data

Gait Variables	Forward AP Motion Factor	ML Motion Factor
Free gait		
Cycle time	−.62	.27
Double support	−.80	.14
Stance	−.79	.19
Peak AP velocity	.92	−.25
Average AP velocity	.91	−.23
Maximum moment arm	.77	−.01
Peak ML CG-CP separation	−.06	.60
Peak ML velocity	.01	.51
CG ML excursion	−.21	.53
ML base of support during double support	−.28	.77
Paced gait		
Cycle time	−.58	.30
Double support	−.69	−.02
Stance	−.67	.14
Peak AP velocity	.90	−.13
Average AP velocity	.91	−.13
Maximum moment arm	.66	.21
Peak ML CG-CP separation	−.05	.65
Peak ML velocity	.10	.58
CG ML excursion	−.14	.17
ML base of support during double support	−.26	.76

DISCUSSION

Our moderately intense exercise program resulted in significantly improved gait stability, which in turn may confer a modest degree of protection from injurious falls among these disabled community-dwelling seniors. To our knowledge, this is the first large sample report of the specific mechanisms whereby gait is improved by strengthening exercise interventions. Most prior studies with sample sizes of 30 or more have not examined functional performance or have used only time-distance gait measures. Lord and associates[23] and Chandler and colleagues[24] separately reported that 10 weeks' strengthening exercise generated about the same strength increases as reported in the present study. They also found improved walking speed in their study's elders. Chandler and colleagues specifically noted that in 100 disabled community-dwelling elders, gait, chair rise, and stair climbing, but not balance or disability,

Table 4: Isometric Lower Extremity Muscle Strength Changes by Experimental Group Among the 120 Participants Who Had Both Values

Group	Knee Extension	Hip Abduction	Hip Extension	Total Lower Extremity*
Exercise				
Base	14.14 ± 4.78 +	8.84 ± 2.59 +	12.04 ± 4.00 +	35.05 ± 9.88 +
Change	2.24 ± 4.04	1.88 ± 2.82	1.90 ± 4.75	6.16 ± 9.29
Control				
Base	14.34 ± 4.51 +	8.32 ± 2.34 +	11.45 ± 4.06 +	33.85 ± 9.88 +
Change	0.63 ± 3.76	1.13 ± 2.44	0.60 ± 3.37	2.46 ± 7.32

Values in table 1 are from all subjects who had baseline data and thus differ slightly (and insignificantly) from those in table 4. Values are mean ± SD at baseline ("Base") + Change at 6-month retest, in kilograms.

* $p < .01$ between exercise and control groups for the three combined lower extremity muscle score changes.

Table 6: ANCOVA Models for 6-Month Change in Forward Motion Gait Factor, for 6-Month Changes in the Mediolateral Gait Factor, and for Individual Mediolateral Variables

	Forward Motion Factor	Mediolateral Factor	Free Gait				Paced Gait		
			CGCPM	CGLVA	CGMLX	BSIHS	CGCPM	CGLVA	BSIHS
Gender	.59	2.79[†]	.89[*]	.77	.87	3.56[†]	1.42[†]	1.97	2.63[†]
Exercise group	.32	−1.89[*]	−.39	−2.22[*]	−.87	−1.61	−.32	−.98	−1.26
Adjusted mean change in exercise group	1.15	−2.02[†]	−.03	−2.43[†]	−1.26[†]	−1.45[*]	−.13	−1.95[*]	−1.35[*]
Adjusted mean change in control group	.83	−.13	.37	−.21	−.39	.16	.19	−.96	−.09
R^2	.09	.23	.33	.36	.51	.33	.41	.31	.20

Increases in the forward motion factor indicate improvement. Decreases in the mediolateral factor and individual variables indicate improvement.

Abbreviations: CGCPM, peak mediolateral center of gravity–center of pressure separation; CGLVA, peak mediolateral velocity; CGMLX, center of gravity mediolateral excursion; BSIHS, mediolateral base of support during double support.

[*] Significantly different from 0 at the .05 level.

[†] Significantly different from 0 at the .01 level.

were positively affected by strengthening exercise. Our data suggest that balance, defined by Chandler and colleagues[24] as "standing still" performance, may not be germane to functional balance needed for gait. Changes in preferred gait maximum moment arm, an indicator of gait stability,[15] correlated significantly with strength changes (table 7). In addition, gait speed increase may not be the correct gait variable to examine; stability at an optimal, functionally adequate gait speed may be more important to elders' well-being than simply walking faster. Because time-distance gait measures cannot examine mediolateral stability, such studies may be inadvertently ignoring the most important contribution of strengthening exercises: improvements in mediolateral stability, such as a decrease in mediolateral center of gravity velocity (table 6).

Table 7: Pearson Correlations Between Total Lower Extremity Strength and Free and Paced Gait Changes From Baseline to 6 Months Posttest in All Subjects in the Exercise Group

Gait Variables	Change in Lower Extremity Strength	
	Free Gait	Paced Gait
ML base of support during double support	−.2099 $p = .068$	−.0317 $p = .413$
Average AP velocity	.291 $p = .018$	.3964 $p = .002$
Peak ML CG-CP Separation	−.2933 $p = .017$	−.1976 $p = .089$
Peak ML velocity	−.1032 $p = .233$	.158 $p = .867$
Peak AP velocity	.2491 $p = .037$	.3781 $p = .003$
CG ML excursion	.1981 $p = .896$	.2841 $p = .968$
Cycle time	−.1982 $p = .079$	−.0577 $p = .345$
Double support—% cycle	−.0907 $p = .261$	−.0916 $p = .263$
Double support—time	−.1126 $p = .213$	−.0966 $p = .252$
Maximum moment arm	.2643 $p = .029$	.2011 $p = .085$
Stance—% cycle	−.2411 $p = .043$	−.1623 $p = .130$
Stance—time	−.2382 $p = .044$	−.168 $p = .122$

One-tailed probabilities reflects directional nature of hypotheses.
Abbreviations: ML, mediolateral; AP, anteroposterior; CG, center of gravity; CP, center of pressure.

As indicated in table 7, lower extremity strength changes in the exercise group correlated ($r = .40$) with paced gait average velocity changes, but not cycle time. The latter is fixed at 1 cycle per second during paced gait. Therefore, these subjects increased their stride length, which is apparently enabled by increasing lower extremity strength. It is not surprising that changes in free gait speed directly correlate (table 7, $r = .29$, $p = .02$) with changes in lower extremity strength.[1,2] It is intriguing, however, that the correlations are so low. Nonlinear (quadratic) regression improved the correlation only to $r = .33$. Hence our data agree with those of Buchner and colleagues,[1] Ferrucci and colleagues,[25] and Chandler and colleagues[24] that strength and gait velocity are nonlinearly related with the greatest functional impact from strength improvements occurring in the weakest subjects.

The mechanisms whereby strengthening exercise may enhance performance are crucial to identifying a new generation of interventions. Our data suggest that addressing elderly patients' functional limitations directly, and not merely hoping that addressing the strength impairment will generalize to functional improvement, may be an important next step in rehabilitation. That is, one must clearly exceed some minimum lower limb strength to be able to walk,[1] but helping patients integrate strength changes into meaningful functional outcomes probably requires more than resistance training alone can offer. The finding from our data and those of Chandler and colleagues[23] that strength explains only a modest amount of variance in functional performance (table 7) indicates that further work is needed to determine the optimal treatment intervention for disabled community-dwelling elders.

In our 215-subject larger sample,[21] we found strength (impairment level) and disability improvements following 6 months' exercise, but no functional improvements. Apparently those analyses examined only time-distance variables. It is likely that the improved gait stability shown in the present subsample occurred among the 215-subject group as well. It is also that these gait improvements enabled the greater social roles (decreased disability) found in the larger sample.[21]

Moderate exercise, such as the home program used by these seniors for 6 months, is currently recommended because it is more accessible than institutional or exercise gym programs. Our gait stability data suggest an additional reason to recommend even a modest, home-based strengthening program. Gait stability clearly deserves further investigation in future studies of exercise among elders.

Enhanced mediolateral stability is probably as important as exceeding a minimum strength value in improving gait performance. Elders who cannot control their balance while they walk will walk more slowly and decrease their functional capacity. This becomes a vicious cycle of inactivity engendering more inactivity.[26] Tinetti's data indicate that functional training, ie, directed physical activity at the whole-person level such as gait training, may be an important feature in rehabilitation for post–hip fracture patients.[27] We suggest that both strength and functional training should continue until a clearer picture emerges of the relative merits of intervening at the impairment or functional level.

Limitations

The present report is the largest sample of disabled elders to be studied with full body kinematics. The sample size may be too small, however, to compensate for statistical error in individual variables. Nevertheless, when factor scores are created, these errors tend to cancel out, giving a clearer picture of the treatment effect on the factor as a whole. Some 77 different baseline diagnoses of disabling conditions were identified among the 120 subjects completing the trial. These various diagnoses probably contribute to the statistical variability, but they also make this sample quite representative of the general geriatric population. Gait may not be a sufficiently stressful outcome variable. Perhaps the treatment effects would be discerned more clearly by analysis of weight lifting, chair rise, or stair negotiation. In future reports we will address those issues, but because most prior studies in the gerontologic literature have assessed the effect of strength on gait as an outcome variable, we chose to focus on gait mechanism in this report.

CONCLUSIONS

These data indicate that moderate exercise results in modest improvements in functional ambulation. Measuring only variables such as average forward velocity, however, does not sufficiently account for changes engendered by strengthening exercises in moderately disabled community-dwelling elders. Mediolateral variables indicative of stability enhancement during gait should be considered in future studies of exercise interventions. Our experience clearly shows that gait laboratory evaluation on a large sample of disabled elders is possible and desirable if one hopes to determine the mechanisms whereby exercise might enhance functional performance.

References

1. Buchner DM, deLateur BJ. The importance of skeletal muscle strength to physical function in older adults. Ann Behav Med 1991;13:91-8.
2. Buchner DM, Cress ME, de Lateur BJ, Esselman PC, Margherita AJ, Price R, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J Gerontol A Biol Sci Med Sci 1997;52:M218-24.
3. Buchner DM, Cress ME, Wagner EH, deLateur BJ, Price R, Abrass IB. The Seattle FICSIT/MoveIt study: the effects of exercise on gait and balance in older adults. J Am Geriatr Soc 1993;41:321-5.
4. Mulrow CD, Gerety MB, Kanten D, DeNino LA, Cornell JE. Effects of physical therapy on functional status of nursing home residents. J Am Geriatr Soc 1993;41:326-8.
5. Fiatarone MA, O'Neill EF, Doyle N, Clements KM, Roberts SB, Kehayras JJ, et al. The Boston FICSIT study: the effects of resistance training and nutritional supplementation on physical frailty in the oldest old. J Am Geriatr Soc 1993;41:333-7.
6. Wolfson L, Whipple R, Judge J, Amerman P, Derby C, King M. Training balance and strength in the elderly to improve function. J Am Geriatr Soc 1993;41:341-3.
7. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year old men and women. Scand J Rehabil Med 1980;12:145-54.
8. Fisher NM, Pendergast DR, Calkins EC. Maximal isometric torque of knee extension as a function of muscle length in subjects of advancing age. Arch Phys Med Rehabil 1990;71:729-34.
9. Iverson BD, Gossman MR, Shaddeau SA, Turner ME Jr. Balance performance, force production, and activity levels in noninstitutionalized men 60 to 90 years of age. Phys Ther 1990;70:348-55.
10. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc 1987;35:13-20.
11. Lord SR, Caplan GA, Ward JA. Balance, reaction time, and muscle strength in exercising and nonexercsising older women: a pilot study. Arch Phys Med Rehabil 1993;74:837-9.
12. Gehlsen GM, Whaley MH. Falls in the elderly: part II, balance, strength, and flexibility. Arch Phys Med Rehabil 1990;71:739-41.
13. Judge JO, Underwood M, Gennosa T. Exercise to improve gait velocity in older persons. Arch Phys Med Rehabil 1993;74:400-6.
14. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. Phys Ther 1993;73:254-65.
15. Krebs DE, Gill-Body KM, Riley PO, Parker SW. Double-blind, placebo-controlled trial of rehabilitation for bilateral vestibular hypofunction. Otolaryngol Head Neck Surg 1993;109:735-41.
16. Jevsevar DS, Krebs DE, Riley PO, Hodge WA. Knee kinematics and kinetics during locomotor activities of daily living. Phys Ther 1993;73:229-42.
17. Krebs DE, Wong DK, Jevsevar DS, Riley PO, Hodge WA. Trunk kinematics during locomotor activities. Phys Ther 1992;72:505-14.
18. Zachazewski JE, Riley PO, Krebs DE. Biomechanical analysis of body mass transfer during stair ascent and descent in normal subjects. J Rehabil Res Develop 1993;30:412-22.
19. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High intensity strength training in nonagenarians: effects on skeletal muscle. JAMA 1990;263:3029-34.
20. Ware JE, Sherbourne CD. The MOS 36-item short-form health survey (SF36). I. Conceptual framework and item selection. Med Care 1992;30:473-83.
21. Jette AM, Lachman M, Giorgetti MM, Assmann SF, Harris BA, Levenson C, et al. Exercise: it's never too late! Am J Pub Health. Forthcoming, 1998.
22. Gorsuch RL. Factor analysis. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1983.
23. Lord SR, Castell S. Physical activity program for older persons: effect on balance, strength, neuromuscular control, and reaction time. Arch Phys Med Rehabil 1994;75:648-52.
24. Chandler JM, Duncan PW, Kochersberger G, Studenski S. Is lower extremity strength gain associated with improvement in physical performance and disability in frail, community dwelling elders? Arch Phys Med Rehabil 1998;79:24-30.
25. Ferrucci L, Guralnik JM, Buchner D, Kasper J, Lamb SE, Simonsick EM, et al. Departures from linearity in the relationship between measures of muscular strength and physical performance of the lower extremities: the Women's Health and Aging Study. J Gerontol A Biol Sci Med Sci 1997;52:M275-85.
26. Brandt Jr EN, Pope AM, editors. Committee on Assessing Rehabilitation Science and Engineering. Institute of Medicine. Enabling America: assessing the role of rehabilitation science and engineering. Washington (DC): National Academy Press; 1997.
27. Tinetti ME, Baker DI, Gottschalk M, Garrett P, McGeary S, Pollack D, et al. Systematic home-based physical and functional therapy for older persons after hip fracture. Arch Phys Med Rehabil 1997;78:1237-47.

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